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Analyzing the Effectiveness of Project-Based Learning and Information Literacy Instruction at a Liberal Arts College

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ABSTRACT

Project-based learning engages students in the collaborative design of generating and seeking answers to questions. Students work independently and creatively, to plan, execute, and make necessary adjustments to produce high-quality work, while developing competent twenty-first-century skills. These skills include critical thinking, collaboration, creativity/innovation, and communication. This work presents a unique partnership between a physics faculty member, a librarian, and a physician in a project-based ultrasound course at a primarily undergraduate institution. Implementing project-based learning, students actively engaged with real-world and personally, meaningful problems. Information literacy skills, such as evaluating and synthesizing information, were also naturally incorporated throughout the completion of student projects. Students responded to general surveys, self-evaluations, peer evaluations, metacognitive surveys, reflections, and attitude tests to help instructors improve, calibrate, and assess the teaching method. Key findings indicate a 9% growth in students' information literacy skills and increased engagement. Additionally, results suggest that students prefer project-based learning compared to traditional teaching. This article highlights the course approach, assessment tools, and student engagement and perception.

1. Introduction

Liberal arts education grounds the values and principles upon which the curriculum at Franklin College is rooted. A liberal arts degree emphasizes a well-rounded and broad intellectual foundation rather than just focusing on training students in one specific field and thus preparing students for diverse career opportunities. Preparing students for their careers, graduate school, or whatever is next, experiential learning, community engagement, and mentored, undergraduate research frame the innovation and intellectual curiosity at the College. Additionally, the liberal arts curriculum emphasizes exploratory learning in the creative arts, scientific thinking, human behaviour, civic learning, international studies, and reasoning and

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values. Problem-solving skills, likewise, are at the core of learning outcomes across campus disciplines.

Fittingly, the ultrasonography course emerged after a local hospital donated ultrasound machines to the Department of Chemistry and Physics in 2014. Faculty (first author of the paper) attended a three-day ultrasound training workshop in January 2017 in anticipation of teaching an ultrasonography course the following month. A theoretical nuclear physicist by training, physics faculty independently commenced the ultrasonography course in the spring of 2017.

Offered every odd spring, Ultrasonography, a 300-level, cross-listed course supports the chemistry, biology, and exercise science curriculums. Ultrasound has a wide range of diagnostic and therapeutic medical applications, and the increasing demand for the use of ultrasound technology in various biomedical fields points to a future in which medical professionals will be required to possess a general knowledge of ultrasound technology. Due to this increasing use of ultrasound in health care, most medical schools are transforming curricula to include medical ultrasound applications (Thapaliya et al., 2024).

The first round of this course was offered in a traditional format with lectures about the principles, uses, and applications of ultrasound technology. Although students did use the ultrasound machines in class, they primarily watched ultrasound videos and attempted to reproduce similar images and results on the machines. As evidenced in course evaluations, students were not challenged to apply the knowledge and skills they learned to real-world problems. The course instructor also recognized low student engagement. As a result, the course was redesigned in a project-based learning format where students would not only engage in personally meaningful research throughout the semester but also learn the value of information literacy.

1.1. Research Questions

With this instructional approach, there was a natural anxiety for change, including concerns about assessing student success, their perceptions of this format, and their ability to learn in the new environment. Three research questions emerged. First, what are ways to efficiently transition a traditional ultrasound class (or similar) into a project-based learning environment to ensure student engagement, and what tools and resources are effective for this? Second, how does project-based learning affect students' information literacy skills? Third, what is the general student perception of project-based learning?

2. Literature Review

2.1. Project-Based Learning

Project-based learning (PBL) is a teaching method in which students gain knowledge by working for an "extended period of time to investigate and respond to an authentic, engaging, and complex question, problem, or challenge" (PBLworks, 2024). Project-based approaches have been attributed to John Dewey, William Head Kilpatrick, and other progressive education theorists since the early 1900s, and PBL's humanistic vision was noted as a natural fit in the medical profession as early as the 1960s (de Graff & Kolmos, 2007; Duke, 2016). Coined by McMaster University in 1969, PBL has been adopted by medical schools not only for its critical thinking and problem-solving value but, also, for its focus on self-regulated, metacognitive learning (Saliba, Mussleman, Fernandes, & Bendriss, 2017).

2.2. Information Literacy

Similarly, the tenants of information literacy (IL) emphasize student learning in the context of self-directed inquiry and extended investigations (ACRL, 2016). Officially adopted by the ACRL Standards Committee in 2000, the Information Literacy Competency Standards for Higher Education have been endorsed by both the American Association for Higher Education and the Council of Independent Colleges. The Framework for Information Literacy for Higher Education (The Framework) emerged in 2016 in response to the changing higher education landscape and the dynamic, complex information ecosystem. The Framework, informed by Wiggins and McTighe [Universal Design] and the Delphi study, consists of six, anchoring concepts. One of the concepts, 'Research as Inquiry', is grounded in the theory that learners "focus on problems or questions within a discipline" (ACRL, 2016). Additionally, this concept emphasizes collaborative investigation, iterative research, and synthesis of diverse materials and perspectives (ACRL, 2016). Furthermore, this frame encourages the learner to build smaller questions out of bigger ones (ACRL, 2016; Steely Library NKU, 2021).

2.3. Metacognition

Metacognition is the ability to understand one's thinking; it constitutes an awareness of one's own thought processes. According to Kuhn and Dean (2004), metacognitive awareness supports critical thinking skills and allows for a greater transfer of knowledge. Dovetailing with information literacy, metacognition requires that learners engage and think deeply about how they acquire and value information; likewise, learning to think critically about one's information needs is part of the research process, as illustrated in The Framework. Typically, metacognition is divided into two cognitive components: knowledge and regulation (Schraw & Dennison, 1994). Relatively speaking, metacognition reinforces an "awareness of one's strengths and weaknesses with specific skills or in a given learning context, plan what's required to accomplish a specific learning goal or activity, identifying and correcting errors, and preparing for learning processes" (Chick, 2013). Such metacognitive behaviours are evident in project-based learning.

2.4. Project-Based Learning and Information Literacy

Early literature reflects the value of project-based learning and collaborative information literacy instruction as effective methods for furthering the information literacy skills of primary and secondary students. For example, Chu, Tse, and Chow's 2011 study indicates that through the "combination of collaborative teaching and inquiry, project-based learning contributes to the development of information literacy" at the primary level. Likewise, proponents of PBL cite its benefits in addressing real-world problems, understanding informational texts, and increasing student engagement, knowledge, and learning (Duke, 2016). Furthermore, research conducted by Kuhlthau, Maniotes, and Caspari (2015, p. 128) recommends a versatile three-member team for inquiry and project-based learning activities in primary and secondary classrooms.

At the collegiate level, literature also reveals the benefits of information literacy instruction in project-based courses. Kate Wegner (2014), research librarian at Chatham University, contends that PBL provides opportunities to acknowledge information literacy, not as a one-and-done session but rather as an "integrated and natural part of a research assignment" (147). Evident in the research of Bakermans and Ziino Plotke (2018), intentional repetition of information literacy instruction in multidisciplinary courses supports improved learning, value, and perceived relevance of student work. On a similar note, the work of Sipriyanti, Permanasari,

and Khoerunnisa (2020) finds a positive relationship between critical thinking, information literacy skills and learning in a project-based chemistry course.

3. Materials and Methods

3.1. Assessment Tools

Before fully examining research question one, a few assessment tools addressing information literacy, student perception, and metacognitive reflection were identified. These tools were chosen for this study in hopes of gathering evidence for the second and third research questions.

3.2. WASSAIL – The Information Literacy Assessment & Advocacy Project (ILAAP)

WASSAIL is a pre- and post-information literacy assessment previously made available through the former Information Literacy Assessment & Advocacy Project (ILAAP). The 15 questions (14 multiple choices, one short answer) span five stages of information literacy: identify, find, evaluate, apply, and acknowledge (Fleming, 2020), specifically, determining student knowledge of a PICO-focused (Population, Intervention, Comparison, Outcome) question, information resources, evaluation criteria, synthesis, and citation.

Previously used by academic libraries and awarded the 2010 Instruction Section Innovation Award from the Association of College and Research Libraries, Wassail fit nicely within the scope of our information literacy sessions. Likewise, it is a convenient open-source platform and immediate data eased our transition to this tool. Furthermore, WASSAIL's question bank provided breadth and depth for each of the five stages of information literacy, and our library consortium routinely recommended use of this tool.

ILAAP discontinued their services in June 2021 but stated that libraries could continue to use the WASSAIL questions per their Creative Commons license. As a result, we moved the pre- and post-test to the Google Forms platform in 2021 and 2023 to continue with the same, consistent set of questions. See Appendix C for the WASSAIL pre- and post-test.

3.3. Project-Based Learning Survey

The Project-Based Learning Survey (adapted from Alper, 2008) consists of three sections. Part one contains two questions from which students choose three of 10, classroom-instruction features that they most and least value. The features include collaborative work, engaging instruction, use of technology, college and career readiness skills, and problem-solving skills, for example. The second part of the survey includes one question devoted to assessing the excitement or nervousness students feel about a project-based course. The final section contains 20, Likert-scale attitude statements; students rank the level to which they agree or disagree with each one. The attitude statements measure preferred learning style and awareness of self-learning. They also help to identify the students' perception and comfort level towards various components of the project-based learning approach as well as their strengths and weaknesses. See Appendix D for the Project-Based Learning Survey.

3.4. 3.2.1 Exit Survey

Each class session ends with students completing a classroom assessment commonly referred to as a 3.2.1 Exit Survey. This survey encourages students to think about three things they learned in the class, two things they found interesting, and one thing they have a question about. The survey allows facilitators to quickly assess student understanding of the discussion and

materials of a particular class session and to address possible questions or concerns that would help to adjust future lessons accordingly. The exit ticket also gives students the opportunity for self-analysis of their understanding or lack thereof.

3.5. Self- and Peer-Evaluations

Logan (2009) found that self and peer evaluations have a meaningful impact on student learning by enabling them to improve their critical thinking and developing self-confidence as learners. Each week, students also complete self- and peer-evaluations outside of class. In these evaluations, each student reflects on their contribution, each member's role, and their overall experience. The idea behind these evaluations is to allow students a chance to self-regulate their own learning, evaluate the work of other group members, provide constructive feedback to their peers, develop collaborative learning skills, and give facilitators insight into each student's contribution and overall group progress.

3.6. Student Search Logs

Heavily touted by information literacy experts, research logs provide opportunity for authentic, formative assessment. Although search logs can be time intensive and require extensive faculty collaboration, they provide evidence of learning and allow students to document how they choose to approach their research (Erlinger, 2018).

Frequently practiced within the College's psychology department, the librarian's prior experience with search logs provided a framework for students to engage further with the information literacy components of defining and identifying information. Students completed a search log as they research and investigate potential PICO questions. The search log encourages metacognitive thinking, strategic searching, and critical reflection, which are commonly associated with project-based learning. See Appendix E for the search log.

3.7. The Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994)

Added as a tool for the 2019 and 2021 academic years, the MAI inventory measures a student's perception of how they learn. Created by educational psychologists Schraw & Dennison, it is a 52-question, true or false inventory, measuring awareness in two categories: knowledge about and regulation of cognition. With any self-reported inventory, potential lack of efficacy and the presence of bias may make them difficult to interpret by both students and faculty. Although new to all course facilitators, Schraw & Dennison's tool stands up well in systematic reviews, particularly in the areas of "understanding of one's ability to learn and remember" and "one's ability to regulate their learning and memory" (Craig, Hale, Grainger, & Stewart, 2020). As a result, this tool became relevant to measuring the ability of students to think about their way of learning.

3.8. Course Design

As assessment tools were selected to identify growth of information literacy skills and to measure student perception of PBL, attention was then given to our research question about course design. Examining course facilitators and student demographics enabled a more seamless integration of the tools into the overall instruction.

3.9. Course Facilitators

Following the recommendation of Kuhlthau, Maniotes, and Caspari (2015, p. 128), a three-member team was established for the 2019, 2021, and 2023 course. Consisting of the physics faculty member, a faculty librarian, and a local physician, this team filled several roles throughout the course.

The faculty librarian (second author of the paper) joined as a course facilitator since PBL incorporates many aspects of information literacy. She participated in multiple class sessions, leading a few lessons about intentional research. Furthermore, she and physics faculty met weekly with students to discuss their research topics, strategies, and proposals in efforts to combine the elements of facilitated, project-based learning, information literacy instruction, and professional expertise.

A physician from the local hospital (third author of the paper) and expert on ultrasound imaging was also included as a course facilitator. He supported the class by providing advanced-level hands-on ultrasound training for students, demonstrating clinical procedures to the class using ultrasonography, and answering students' complex medical questions related to the course or research projects. He also facilitated hospital visits to provide students with additional insight into how ultrasound imaging is used with real patients.

A few weeks prior to the start of the class, the course facilitators conducted several meetings to discuss roles, syllabus, course objectives, assessments, and evaluations of what worked well and what did not during the previous course offering. The necessary adjustments to the course were done accordingly and carefully based on student course and self-evaluations. Both PBL and information literacy components were intentionally added to the syllabus and defined for students, so they would not only know the terms PBL and information literacy, but so they would be practiced and applied throughout the course. The first three class sessions set the stage for the semester. See Appendix A for class schedules and assignments.

3.10. Student Demographics

The course primarily consists of students majoring in chemistry, physics, exercise science, biology and biomedical science. Enrolling 53 students since 2017, juniors and seniors make up most of the course enrolment, while 75.5% self-report having previous instruction from the Colleges' librarian either during a class or in a one-on-one meeting. See Figures 1 and 2 for a closer look at these demographics.

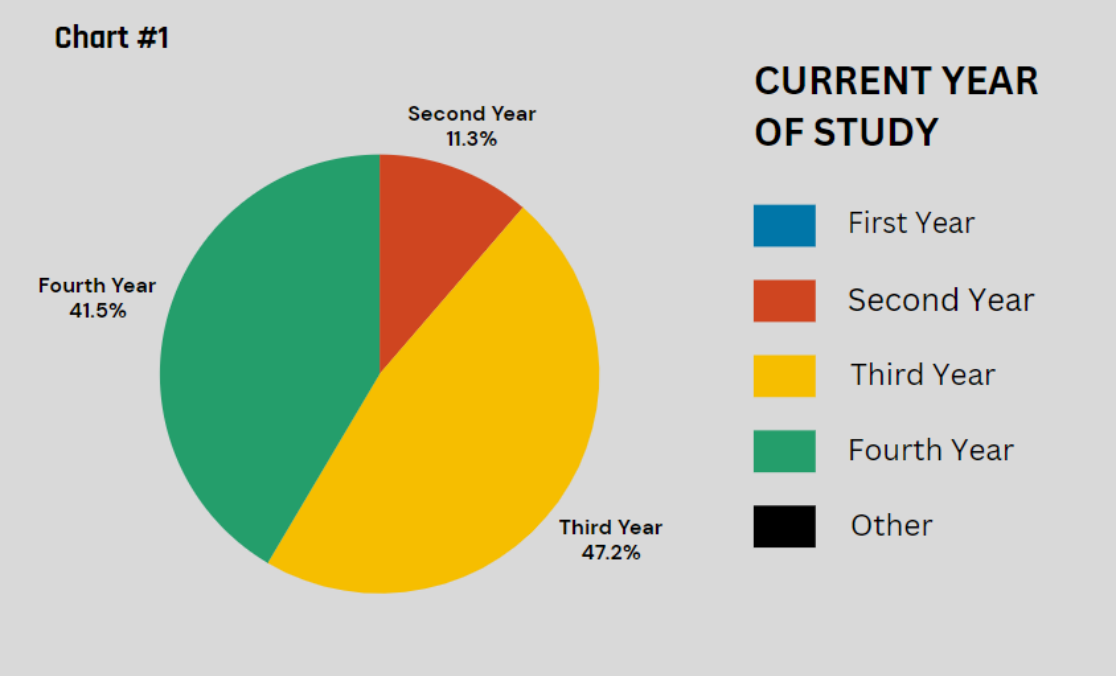

Figure 1. Student Year of Study (2019, 2021, 2023)

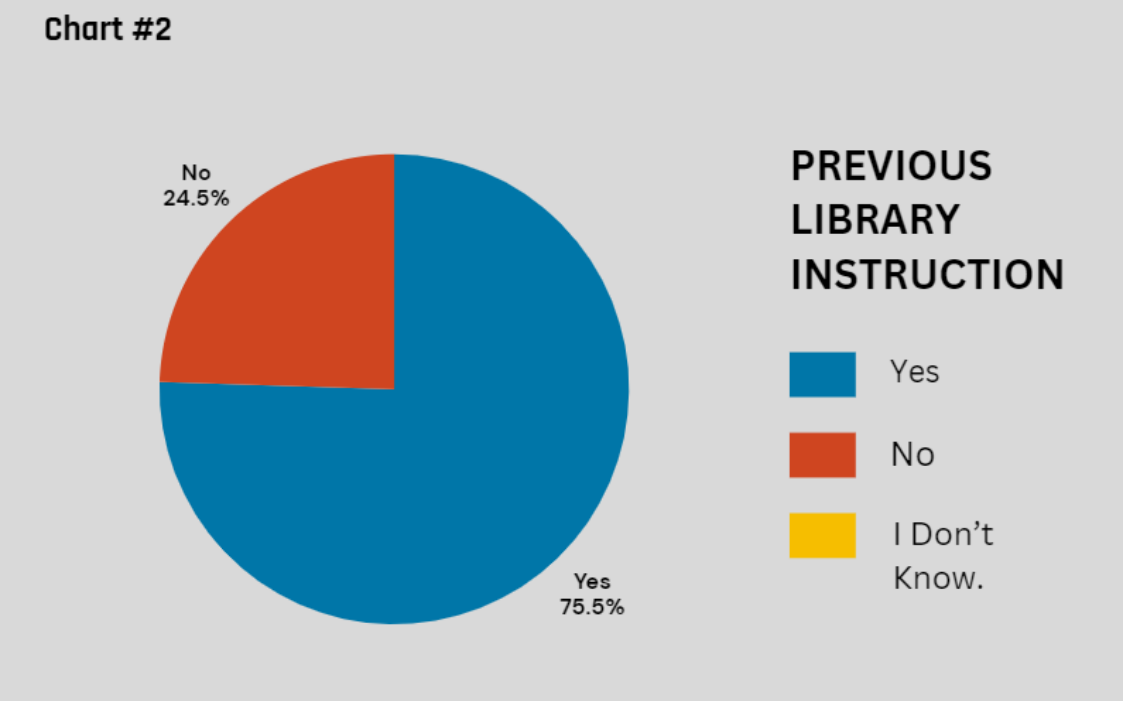

Figure 2. Previous library instruction (2019, 2021, 2023)

3.11. Course Design – First Session

Scheduled in two-and-a-half-hour segments, the three-hour course meets weekly. The course covers four sections: introductory, musculoskeletal, cardiovascular, and abdominal ultrasound through hands-on training, orientation, and manipulation. Students tackle a semester-long, Institutional Review Board (IRB)-approved research project through the lens of a PICO question, strategic academic online searching, critical evaluation of information, intentional application of research, and ethical acknowledgement of information. Furthermore, students complete their research as a team assuming roles such as project manager, planner, and scribe.

During the first meeting, students explore the fundamental concepts of PBL, complete a PBL attitude survey, and brainstorm potential problems to research. Additionally, the faculty librarian attends this class session, and students explore the five components of information literacy: defining, finding, evaluating, applying, and acknowledging information through a short video and a librarian-facilitated, hands-on, small group activity in which students categorize research behaviours. This enables students to critically think and problem-solve together, as they organize 25 research behaviours into five sets of five. Sparking authentic discussion, students discover the iterative process that is research. See Appendix B for the five components of information literacy.

Before the first session ends, students complete an information literacy pre-test. Additionally, they complete the Project-Based Learning Survey and a 3.2.1 Exit Survey.

3.12. Course Design – Second Session

Before the second-class session, students individually identify a problem or challenge that would potentially root their research throughout the course. In small groups, students share their project ideas through "wisdom circles" as the librarian guides students through the process of defining their research need and identifying resource types to explore. These topic discussions and the 3.2.1 responses assist facilitators in determining which small groups (2-3 students) might work well for their semester-long, project investigation.

3.13. Course Design – Third Session

Students arrive at the third, class meeting with the intentionality of narrowing their research topics and creating relevant searches. The librarian leads a group reflection of the search process as students discuss the feasibility, weakness, challenges, and budgetary needs of their research ideas. Research topics are then narrowed and finalized, and student groups are formed. Below are a few topics of the research projects that students have worked on in this course.

- Study of the Effects of Caffeine on Blood Flow, Arterial Size, and Oxygen Saturation Level of College Students using Ultrasound
- Study of the Effectiveness of Ultrasonic Cavitation Procedure in Reducing Adipose Tissue in Female Athletes
- Investigating the Effectiveness of Cold Compression Versus Heat Compression on the Size and Blood Flow in the Brachial Artery
- Effects of Acute Shockwave Ultrasound Therapy on Blood Flow in Physically Active College Students
- Investigating the Correlation Between Anterior Chamber Length and Ocular Dominance using Ultrasound

3.14. Course Design – Project-Based Research

Since student projects involve human subjects, projects are later approved by the Institutional Review Board (IRB) of the college. A member of the IRB committee is invited to the class to provide information to the students about IRB best practices and the submission process as preparation for the proposal-writing process.

In the following week, students prepare a first draft of the research proposal, and the facilitators of the course provide feedback for improvements. Students produce at least two more iterations of the draft and finally submit it to the IRB by week six. The turnaround time for IRB proposals is about a week, and once they are approved, students start recruiting the subjects (from the

student body on campus) during week seven for their research. Between week three and spring break, students receive lessons and hands-on training on ultrasound imaging during the class so that they are knowledgeable and skilled enough to confidently use the ultrasound machines to collect data without any extensive help or intervention from the facilitators of the course. Since ultrasound is increasingly becoming an important diagnostic tool in veterinary medicine, students in this class also get the opportunity to practice ultrasound imaging of animals including dogs and fish.

As soon as students return from break, they start collecting data for their research which occurs from week ten to week twelve. The class does not meet during these three weeks, and students use this time to coordinate schedules for ultrasound measurements. Students are, however, required to update the facilitators about the progress and any concerns of their work on a regular basis during this three-week time.

Following the completion of data collection, students analyse and discuss their results with the class. This is done through PowerPoint presentations when the class reconvenes during week thirteen. These presentations also serve as a practice opportunity for the College's Scholar's Day during week fourteen. They also receive constructive feedback from both their peers and course facilitators. Scholars' Day is a day-long event occurring every spring where faculty and students showcase their research and creative expression to the entire college and community. During week fifteen (the last week of classes), students complete evaluations and surveys that help the facilitators with future directions of the course.

4. Results

4.1. WASSAIL - The Information Literacy Assessment & Advocacy Project (ILAAP)

WASSAIL – The Information Literacy Assessment Pre- and Post-Tests indicate improvement in students' information literacy skills by 7.4% in 2019, 7.2% in 2021 and 0.2% in 2023. Students grew in all areas but one. The 'acknowledge' component of information literacy remained steady indicating that student knowledge about citing sources, for example, maintained its average.

Although student scores in 2021 nearly replicated those of 2019, the 2023 pre-test scores were 0.9% lower than the previous two years. In 2023 students initially scored higher in the areas of 'identify' and 'find'. Overall, students most improved in the areas of 'identify,' 'find,' and 'evaluate' but made little progress in the areas of 'apply' and 'acknowledge' on the post-test. Through three iterations of the course, student growth of information literacy skills improved. The largest knowledge gains occurred in 2019 and 2021. See Table 1 for overall test scores and correct responses by information literacy component.

Table 1.
Percentage of correct response by information literacy component

Question	Information Literacy Skill	2019 Pre-Test	2019 Post-Test	2021 Pre-Test	2021 Post-Test	2023 Pre-Test	2023 Post-Test
1, 2, 3	Identify	64%	73%	73%	88%	76%	63%
4, 5, 6	Find	68%	73%	49%	58%	70%	60%
7, 8	Evaluate	59%	78%	59%	82%	68%	85%
9, 10	Apply	93%	95%	96%	91%	82%	75%
11, 12, 13, 14	Acknowledge	67%	67%	71%	72%	66%	69%

4.2. The Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994)

Self-scoring their perception of their own learning, students ranked highest in the knowledge area of 'debugging strategies' and lowest in 'evaluation' both within the 'regulation of cognition' category. Notably, students scored best in the three areas of knowledge categorized as 'knowledge about cognition.' The results of the MAI indicate that students perceive themselves as learners who identify knowledge better than they plan, monitor, and assess their learning. See Table 2 for the combined, average MAI self-scores from 2019 and 2021.

Table 2.
MAI self-score averages (2019, 2021)

Knowledge	Category	Possible Score	Self-Score Avg.
Declarative Knowledge	Knowledge about Cognition	8	6
Procedural Knowledge	Knowledge about Cognition	4	2.7
Conditional Knowledge	Knowledge about Cognition	5	4.2
Planning	Regulation of Cognition	7	4.7
Information Management	Regulation of Cognition	10	7.8
Comprehension Monitoring	Regulation of Cognition	7	4.9
Debugging Strategies	Regulation of Cognition	5	4.8
Evaluation	Regulation of Cognition	6	3.3

4.3. Project-Based Learning Survey 2019, 2021, 2023

Administered during the most current, three iterations of this course, the project-based survey was completed by 42 students. Notably, the survey responses indicate that students most value engaging instruction, the use of technology, and course content that is real-world preparation and enhances their problem-solving skills. On the other hand, students least enjoy collaborative grading measures and preparation for state achievement tests. Seventy-eight percent of students also wrote that they were excited about the project-based learning course. Responses to questions #9 and #23 reveal that 80% agree or strongly agree that they enjoy creating scientific questions and researching answers, and 70% strongly agree that they are motivated by real-world and personally meaningful projects.

4.4. 3.2.1 Exit Survey Summative Responses, Sessions One and Two

Completed each class session, the 3.2.1 survey summative responses indicate immediate retention of information literacy-related skills. At the end of the first session, students mentioned something specific to information literacy in 30% of the responses; many commenting on its five components. One student stated, "Information literacy is more than just peer-reviewed journals." Likewise, students mentioned the PICO question model as "new" learning in 23% of the responses.

4.5. Information Literacy Search Logs 2023

Students completed information literacy search logs in 2019, 2021, and 2023; however, a thorough assessment was only conducted in 2023. Initial observations indicate that 60% of the students noted valid results as a challenge with their PICO question and literature searches. Within these logs, students commented on the lack of research available about their specific PICO question and the potential generality of the results within the published students and potentially within their own. Additionally, students self-strategized their search by evaluating relevancy and keywords. See Table 3 for a breakdown of the percentage of student logs considering specific strategies.

Table 3.
Noted Search Strategies in Student Search Logs

Percentage	Strategy
60%	Look for valid, relevant results
25%	Reframe PICO question
35%	Reconsider keywords

5. Discussion

5.1. Interpretations and Implications

In this study, we found that student's perception towards the project-based learning was mostly positive. Based on the related surveys, 78% of the respondents were excited about this approach. This was also evident in the student course evaluations administered at the end of the semester. Below are some of the comments made by students in their course evaluations.

- While we were still on campus, the presentation of material was very hands on and helped me learn about the different ultrasound machines. I also learned a lot about myself through the metacognition activities.
- I think the class layout was very efficient for the type of course. I enjoyed how it was all based on your own merit.
- I enjoyed the project-based format of the class a lot. I feel it helped us learn quicker and we learned our own style of using ultrasound that is most comfortable for us.
- I love the approach to teaching as we were learning from our peers, and he [instructor] was here to help when we needed it.

Based on the course evaluations, we also found that students biggest concern is each team member contributing equitably. Although students complete multiple peer evaluations in the course, we feel that allowing each group to spend time during class each week to distribute their work to the team members might help to alleviate this issue. Many students also suggested making this class a two-semester course instead of one so that students have enough time to collect sufficient data for their work. We recognize that this is not feasible because of faculty workload. However, some students have continued their projects as an independent research study in following semesters. The overall positive student impression of the class and the project-based approach gives us confidence to continue to offer this course using this format.

The intentional focus of information literacy in this project-based course shows promise. Most significantly, tests scores reveal a growth in multiple areas of information literacy each time the course is taught. It is also rewarding to see significant growth in the skill of ‘evaluate’. This might be related to the fact that the library began teaching lessons about evaluating information, of both popular and scholarly sources, in first-year seminar courses in the fall of 2021. The initial pre-test scores in 2023, 9% higher than previous classes, might be explained by the fact that juniors had previous library instruction in this area. Notably, it is peculiar that 2023 post - test scores dropped in the areas of ‘identify’, ‘find’, and ‘apply’. Some of that may be due to the post-test being administered on the last day of class. Overall, however, the information literacy scores mimic classroom observations of student learning.

Metacognitive scores echo our classroom observations as well. There is little surprise that students rate themselves as better learners when they plan, monitor, and assess their learning and that they acknowledge this as an area they are less confident in. Throughout the teaching of each course, facilitators had to assist with student planning and monitoring of their projects through regular meetings and check-ins. To further enhance metacognitive assessment, more intentionality is needed. In addition to the MAI and a few questions on the search logs, more

attempts could be made to measure growth in this area. For example, it might be valuable to designate time to circle back to the MAIs later in the semester in small, student focus groups or in a one-on-one setting with a course facilitator. Regardless, more attention in this area is warranted to better understand the relationship between metacognitive learning, information literacy, and PBL.

5.2. Limitations

Since the course's inception, each iteration has varied from the prior one. The addition of a librarian facilitator and the onset of COVID created immediate changes in the overall delivery of the course and the elimination of the hands-on research project as students were unable to return to campus to work with their participants. As a result, the 2021 academic year schedule allowed for full inclusion of a librarian facilitator, complete follow-through with pre- and post-testing, and finished research projects and dissemination at Scholars' Day.

In the spring of 2023, changes in employment created a challenging dynamic, as the faculty librarian was promoted to Director of Library Services & Assessment. This posed a strain on her time while she managed her new library role and led a search for a new librarian simultaneously.

And, as many educators might attest, it is challenging to make sure that every student equitably contributes to their group's project, and some student projects could benefit from a longer timeframe. Over the years, we have received very positive feedback from students about this class, and there seems to be a keen desire for students in taking this class. When the class was first offered in 2017 in a traditional format, there were only eight students enrolled in this class. In the spring of 2024, there were 21 students taking this class, which is a fairly large number for an elective course at the College with a full-time student enrolment of a little over 900.

6. Next Steps

6.1. New Minor

We have developed a biomedical physics minor based on this class; student interest in this minor is very strong. We are glad that student enthusiasm in this minor is making a good case for a biomedical physics major. Furthermore, this model could be implemented in other courses, such as Radiation and Health and Biomedical Optics which are taught by the same instructor. Since ultrasound technology has such wide applications, diagnostically and therapeutically, the exercise science program, athletic training program, and physician assistant program at the College are on board about the prospect of using ultrasound for teaching and research in their respective areas. And because many departments on campus are excited to use these units in their programs, we collectively reached out to college administration, and they supported the purchase of ten units of handheld ultrasound probes that can be connected to a smartphone, increasing the accessibility of these units. These tiny portable devices have been very beneficial for this class particularly with research projects that need data collection on the athletic fields.

6.2. Open Access Textbook

Based on the notes and lab manuals on ultrasound principles and applications that were prepared for the course over the years and expanding the focus a little more, we were able to publish an open resource textbook (Thapaliya et al., 2024). It is freely available online to users from all around the world. The textbook covers a wide range of topics, including the principles

of ultrasound physics, its applications in various medical specialties, and practical aspects of diagnostic ultrasound.

7. Conclusion

When we started offering this class in a traditional format, there was a clear lack of student motivation and engagement. Seemingly confirmed through our assessments, project-based learning can be a useful tool to allow students to take the ownership of their own learning while putting themselves in the central focus in that process. Because of this, student enthusiasm and engagement in the course increased significantly. The approach has allowed students to conduct real-life and personally meaningful research projects. Because of this, we noticed that students put sincere efforts in the different tasks in order to make sure that their project is successful. We also found that since students are planning, managing, and evaluating their own learning, their confidence level improves over time. The collaborative nature of PBL enabled students to practice collective problem-solving which we believe is an important life and social skill to have.

Based on our findings, we strongly recommend the use of the project-based learning approach in classrooms within most disciplines. We acknowledge that adopting PBL for a class is a time-consuming process and sometimes overwhelming for the instructor. For us, the lack of knowledge and experience with project-based learning was daunting, but the pooled expertise of each course facilitator eased our navigation of the many scattered ideas and resources found online. We were able to research and identify various tools and resources that made the transition to project-based learning from traditional format effective.

Based on the need of the course and assessment, over the years, we have been able to modify those tools and resources to make them more efficient. For interested instructors, our recommendation would be to co-teach the class with other interested instructors if feasible. This will not only allow to manage the time constraints but also brainstorm ideas for proper implementation of PBL and sharing responsibilities. It is to be noted that identifying suitable teaching partner is essential and sometimes it takes time to build a coherent teaching relationship with them. It is also important to know the strengths as well as weaknesses of everyone involved in teaching a PBL class and be open minded about them.

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Appendix A

Class schedules and assignments for the first three weeks of classes

Day	Class Schedule	Assignments
First day of class	• Overall Course Introduction by the facilitators. • Students complete PBL attitude survey. • Students receive lesson on Information Literacy (IL) from the librarian facilitator. • Students complete IL assessment. • Students discuss ways in which they could ensure equality within a research group of the class. • Students spend time brainstorming possible topics. • Students complete 3-2-1 exit ticket.	Due before second day of class • Students independently identify a challenging problem or question that will potentially take the form of the project for this course. • Students prepare a one-page summary of the project idea to be shared with the rest of the class. Students also develop at least one alternative idea. • Students complete a self-evaluation.
Second day of class	• Each student shares their project idea (5-minute presentation) with the rest of the class. • Students complete MAI survey. • Student groups are formed. • Students develop goals for the overall PBL project. • Students receive IL lesson the search process from the librarian/co-facilitator. • IRB best practices lesson from an IRB member. • Students are introduced to the concepts of waves and ultrasound along with hands-on activity with the ultrasound equipment. • Students complete 3-2-1 exit ticket.	Due before third day of class • Each student group meet and finalize the problem that would take the form of project for this course. Each group submit a one-page summary providing information about their final project. • Students complete the IL search log and engage with the group members in a rigorous, extended process of posing questions, finding resources, and applying information. • Students complete self- and peer-evaluations.
Third day of class	• Discussion on how the group worked together (how long, how many hours, how things were coordinated, etc. just about anything that happened during the group meetings). • Discussion of feasibility of each proposed project idea within and across groups. • Discussion of any budgetary needs. • Discussion on the search log. • Students continue to practice imaging with the ultrasound machine. • Students complete 3-2-1 exit ticket.	Due before fourth day of class • Students meet in person with the librarian facilitator for feedback on the search process and search log. • Students write a first draft of forms that would be submitted to IRB. • Students complete self- and peer-evaluations.

Appendix B

Five Components of Information Literacy Lesson

Anticipatory Set (15 minutes):

- Think - Pair - Share -- How do you conduct research? Create a map.

Student Learning Outcomes (one-two):

- Students will identify the five components of information literacy.
- Students will analyze the importance of one of the five components.

ACRL Framework (one):

- Research as Inquiry

Input/Model (5 minutes):
Share the following information…

- ALA (1989) definition of information literacy, "...ability to locate, evaluate, and use effectively the needed information"
- ACRL (2016) IL enables learners to "master content and extend their investigations, become more self-directed, and assume greater control over their own learning"
- Shapiro and Hughes (1996) "...critical reflection on the nature of information itself, its technical infrastructure, and its social, cultural, and even philosophical context and impact…"
- Simmons (2005) "think of research not as a task of collecting information, but instead as a task of constructing meaning"
- 5 components of IL - identify, find, evaluate, apply, acknowledge

Guided Practice (15 min):

- Working with a partner, students will match research behaviors with each of the five IL components.
    - Each of the five IL components will be displayed throughout the classroom at stations. Station one is identify, station two is find, etc.
    - Each partner set will be given an envelope containing five research behaviors.
    - They will walk around the classroom and match each behavior with an IL component.

Research Tool (5 minutes):

- Introduce the students to the Research Guide.

Appendix C

WASSAIL: Information Literacy Pre- and Post-Test (Correct Answers in Green)

Identify

1. Which research question best narrows a topic about ultrasound and soccer players?
    - What are the effects of ultrasound therapy in the recovery process of knee injuries among undergraduate soccer athletes?
    - What are the effects of ultrasound therapy in the recovery process of a knee injury?
    - What are the effects of ultrasound therapy for knee injuries among undergraduate soccer athletes?
    - I don't know.
2. Which type of source is generally written for a specific profession or industry and primarily contains information about industry trends, professional skills, and organizational news?
    - Popular magazine
    - Trade journal
    - Peer-reviewed journal
    - I don't know.
3. What type of source best defines an empirical, scholarly article?
    - Primary source
    - Secondary source
    - Tertiary source
    - I don't know.

Find

4. Which set of keywords best fits the research question: "What are the effects of daily caffeine consumption on resting heart rate in sedentary patients?
    - Caffeine, heart rate, patients
    - Caffeine consumption, heart rate, sedentary
    - Caffeine, heart rate, sedentary
    - I don't know.
5. Which set of search terms would give you the *least* number of results?
    - shoulder AND elbow
    - shoulder AND elbow AND pitching
    - shoulder OR elbow
    - I don't know.
6. Which parts of a library database record are best for revising or considering specialized search terms?
    - Author and source title
    - Publication type and journal information
    - Subjects and abstract
    - I don't know.

Evaluate

a. Which strategy will help you evaluate the credibility of a source?
   - The CRAAP test
   - The FLY test
   - The SMUG test
   - I don't know.

7. Which strategy will help you check the authority, accuracy, and purpose of a source?
   - Lateral reading
   - Vertical reading
   - Speed reading
   - I don't know.

Apply

8. What should you do if you discover a current study that contradicts some of the claims you've found in other sources?
   - Consider the outdated studies to be proven incorrect.
   - Incorporate the current study into your research along with the previous claims.
   - Ignore the current study because it is too current to be validated yet
   - I don't know.
9. What is the process of connecting the ideas and findings of multiple sources in order to show their similarities and differences?
   - Paraphrasing
   - Synthesizing
   - Quoting
   - I don't know.

Acknowledge

11. Which of the following is the journal title in this citation?
Davis, K. A., & Wilson, T. (2019, February). Thermal conductivity and one-dimensional materials. *Applied Physics Letters*, *12*(4). 56-75. https://doi.org/10.1086/286481

   - Davis & Wilson
   - Thermal conductivity and one-dimensional materials
   - Applied Physics Letters
   - I don't know.

12. Which of the following is a scholarly journal article?

- American Academy of Orthopaedic Surgeons. (2021, August). *Shoulder injuries in the throwing athlete*. OrthoInfo. Retrieved January 27, 2022, from https://orthoinfo.aaos.org/en/diseases--conditions/shoulder-injuries-in-the-throwing-athlete/

- Ultrasound can ease shoulder tendinitis. (1999, Jul 30). *Austin American Statesman* http://ezproxy.franklincollege.edu/login?url=https://www.proquest.com/newspapers/ultrasound-can-ease-shoulder-tendinitis/docview/255672359/se-2?accountid=26240
- Marshall, N. E., Keller, R. A., Van Holsbeeck, M., & Moutzouros, V. (2015). Ulnar collateral ligament and elbow adaptations in high school baseball pitchers. *Sports Health*, *7*(6), 484–488. https://doi.org/10.1177/1941738115604577
- I don't know.

13. What is the main purpose of an institutional review board?

- Protect human participants
- Critique literature reviews
- Suggest research ideas
- I don't know.

14. Which of the following is NOT one of the components of information literacy?

- Apply
- Evaluate
- Acknowledge
- Conceal
- Find

15. In your own words, define information literacy?

Demographic

16. What is your current year of study at Franklin College?

- First year
- Second year
- Third year
- Fourth year
- Other

17. Have you previously had instruction from a librarian, either during class or one-on-one meeting?

- Yes
- No
- I don't know.

Appendix D

Project-Based Learning Survey

Please select three features of classroom instruction that you **MOST** value from the list below:

- o Work collaboratively with people with different skills and background
- o Engaging instruction that motivates the students to take an active role in learning
- o Opportunities to enhance use of technology
- o Preparation for the real world in which we compete for jobs
- o Preparation for the college and career readiness skills that will be assessed on new state achievement tests
- o Driving my own learning through inquiry
- o Become proficient communicators
- o Enhancing my critical-thinking skills that lead to solving problems
- o Grading is based on the collaborative efforts of the entire group
- o Instruction promotes the students' deep understanding of course content

1. Please select three features of classroom instruction that you **LEAST** value from the list below:

- o Work collaboratively with people with different skills and background
- o Engaging instruction that motivates the students to take an active role in learning
- o Opportunities to enhance use of technology
- o Preparation for the real world in which we compete for jobs
- o Preparation for the college and career readiness skills that will be assessed on new state achievement tests
- o Driving my own learning through inquiry
- o Become proficient communicators
- o Enhancing my critical-thinking skills that lead to solving problems
- o Grading is based on the collaborative efforts of the entire group
- o Instruction promotes the students' deep understanding of course content

Project Based Learning is a teaching method in which students gain knowledge and skills by working for an extended period of time to investigate and respond to an authentic, engaging, and complex question, problem, or challenge.

You will be working on a project for the whole semester for solving a real-world problem or answering a complex question. You will demonstrate your knowledge and skills by creating a public product or presentation for a real audience towards the end of the semester. You are expected to develop deep content knowledge as well as critical thinking, collaboration, creativity, and communication skills.

2. I am very _____ (excited/nervous) about this course being project-based and completely student-driven.

Circle a number to rank your attitude for statements below on a **1-5** scale

(1=strongly disagree—5=strongly agree)

3. I expect to do very well in this class. (1 2 3 4 5)
4. I prefer lecture-based instruction. (1 2 3 4 5)
5. I prefer learning individually. (1 2 3 4 5)
6. I am open to experimenting new ways of learning. (1 2 3 4 5)
7. I prefer engaged learning, hands-on, project learning. (1 2 3 4 5)
8. I enjoy creating scientific questions and researching answers. (1 2 3 4 5)
9. I am willing to change my ideas when evidence shows that the ideas are poor. (1 2 3 4 5)
10. I enjoy and value collaboratively working in a research group. (1 2 3 4 5)
11. I can make valuable contributions to a group project. (1 2 3 4 5)
12. I think working in a group is a waste of time. (1 2 3 4 5)
13. I don't want to have an active role in group studies. (1 2 3 4 5)

Circle a number to rank your attitude for statements below on a **1-5** scale

(1=strongly disagree—5=strongly agree)

14. I dislike my peers evaluating me. (1 2 3 4 5)
15. I can't learn the instructional materials myself if a facilitator does not help me. (1 2 3 4 5)
16. I am confident that I can come up with a project idea for this class without the help of a facilitator. (1 2 3 4 5)

17. I am a poor judge of my own learning. (1 2 3 4 5)

18. When I need help, I ask for it. (1 2 3 4 5)

19. I can develop a different hypothesis myself to solve a problem.
(1 2 3 4 5)

20. I need help getting started on solving a problem. (1 2 3 4 5)

21. I can integrate my prior knowledge to solve a problem. (1 2 3 4 5)

22. I am motivated when I study real-world and personally meaningful projects.
(1 2 3 4 5)

23. I am able to combine the different disciplines to solve a problem.
(1 2 3 4 5)

Appendix E

Search Log

In the space below, describe the **topic** that you will attempt to work with in this class.

Try to identify **four PICO elements** for your research topic. Write these PICO elements in the appropriate spaces below.	
PICO	**PICO Elements**
Patient/Population (**P**)	
Intervention (**I**)	
Comparison (**C**)	
Outcome (**O**)	

Identify the possible **opportunities and challenges** of your **PICO elements**.	
Opportunities	**Challenges**

Combine each of your four PICO elements into a research question. Write your **PICO question** below.

List the main **keywords/concepts** from your PICO question to use in a database search. Then, record **similar terms/phrases or synonyms** for each keyword.				
	Patient/Population	Intervention	Comparison	Outcome
Keywords from PICO question				
Similar Terms				
Similar Terms				
Similar Terms				

Choose at least **two relevant databases** and record their names below. Here is a list of several databases in addition to the few on the FIND page of the research guide. Construct at least **three searches** using Boolean operators, and write them in the appropriate spaces below. Conduct all three searches and record notes about each.		
	Database #1:	Database #2
Search #1		

Your Notes		
Search #2		
Your Notes		
Search #3		
Your Notes		

Organize any relevant information you have found thus far and write it down below. **Record permalinks below or save article downloads** in a secure folder. Make sure to **evaluate** your sources using the CRAAP test. Also, make notes below about your organizational methods.
Plan your next steps here. Do you need to reconsider your topic and hence, rewrite your PICO question? Explain.
In your search process, did you consider synonyms? If yes, explain below why you used synonyms and what differences you found. If not, try using a few synonyms for the keywords in your search, and explain your findings.

Summarize how you feel about your research so far. What are you comfortable or happy with? What do you wish you knew more about?